REVIEW OF THE SUGAR CANE ETHANOL PATHWAYS IN CA-GREET 2.0

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EXECUTIVE SUMMARY

The California Air Resources Board (Board/ARB) is proposing to re-adopt the Low Carbon Fuel Standard (LCFS) regulation and to include updates and revisions compared to the previous regulation. The ARB staff will bring a new LCFS regulation to the Board for consideration in February 2015. The proposed LCFS regulation will contain revisions to the 2010 LCFS as well as new provisions designed to foster investments in the production of the low-CI fuels, offer additional flexibility to regulated parties, update critical technical information, simplify and streamline program operations, and enhance enforcement.

To address these issues with fuel pathway certifications, staff is proposing a two-tiered system in which conventionally produced first-generation fuels, such as starch- and sugar-based ethanol, would fall into the first tier. Next-generation fuels, such as cellulosic alcohols, would fall into the second tier.

ARB has stated that the Tier 1 process simplifies and expedites the certification process by providing applicants with a streamlined CI calculator that computes pathway CIs using a base set of input parameters needed to determine a Tier 1 pathway CI. This method will use the CA-GREET 2.0 model. This model is a California version of the GREET1 2013 model.

Scope of Work

This work reviews the sugarcane ethanol pathways in the new CA GREET model to ensure that they function properly and utilize the best available science. The review has considered the following questions.

Are the pathways consistent?

It is important that the model uses the same basic approach, including system boundaries and assumptions for all of the ethanol pathways and ideally all of the fuel pathways.

Does the model ask for the key input parameters?

The model will use a combination of default values and user defined inputs to model specific plants. It will be important that all of the important parameters that change from one plant configuration to another are user defined inputs and are not default values.

Does the model reflect the actual practices?

The model must include all of the actual steps in the production process for it to be useful. If it doesn't, some plants will not be able to generate accurate values.

Does the model have the correct background data and are the calculations correct?

Finally it is important that the model contains the best available background data and that the model functions properly. Background data would include the default values, biomass and fuel characteristics, and other inputs.

A significant number of issues were identified. Most of the issues results in the model returning values that are lower than what would be returned if the issues were addressed properly.

Sugar Cane Farming Summary

The CA GREET model does not apply different energy use factors to sugar cane farming even though the two scenarios with mechanical harvesting require almost twice the energy of a manual harvest system. A mechanical harvest system with 100% of the energy supplied by diesel fuel will have GHG emissions of 7.54 g CO_2eq/MJ.

There is evidence that the crop residues that are left on the field are reducing the synthetic nitrogen that is required. The proportion of nitrogen from fertilizer and from crop residue should vary depending on whether or not there is straw burning. The CA GREET model is assuming that there is no difference in nitrogen requirements between burned and unburned fields, an unlikely scenario.

Although there is significant uncertainty regarding the appropriate N_2O emission factor for sugar cane production, the best information in the peer reviewed literature would suggest that the 1% EF1 factor used by CARB is too low. The impact of increasing this to 1.5% is an increase in sugar cane N_2O emissions of 2.83 g CO_2eq/MJ.

Straw Burning Summary

The straw burning emissions appear to be too low by about 4.42 g CO_2eq/MJ as a result of using the IPCC emission factors for Ag residue burning rather than the values for grassland and savanna burning. This increase would be reduced to about 2.5 g CO_2eq/MJ if the nitrogen from the burned straw was not returned to the soil as discussed in the previous section.

Cane Transport Summary

The model should be changed so that the share of the delivery of cane by medium duty trucks and by heavy duty trucks is a user input. The truck energy requirements are the same as for corn ethanol.

Ethanol Production Summary

There are several errors in the CA GREET model related to the transfer of information from the T1 Calculator sheet to the core of the model. These include:

1. Nuclear and biomass power shares of the power generation are transposed when they are transferred to the ETOH sheet.
2. The inputs for sulphuric acid and ammonia are input into the cells for enzymes when they move from the T1 Calculator sheet to the ETOH sheet. Entering non-zero values will produce extremely high and erroneous GHG emissions.

There is also the potential for misinterpretation of the input values. The input for Residual oil is really the quantity of used lubricants that are burned in the plant and not the input of residual oil.

The quantity of biomass that is burned at the plants is hard coded in the model. Not all mills burn all of the bagasse on site; some sell a portion to other local industries. The emissions for these operations will be overestimated. The biomass from the T1 Calculator sheet is transferred to the ETOH sheet, but once it goes there it is not included in any calculations. A proper modelling would require the mills to enter the bagasse consumed and not hard code those quantities. The current model would underestimate the emissions from mills that imported bagasse from another facility or used some straw from the fields to produce more electric power for export.

Transportation Summary

There are issues with the ocean shipping calculations in GREET for many of the fuels, including sugarcane ethanol. The issues for sugar cane ethanol include:

1. The shipment size of 22,000 tons is too high and is not a user input.
2. Ethanol, uniquely of all of the fuels in CA GREET, is not charged with a backhaul.
3. The energy use for ocean shipping is calculated but the calculations underestimate the energy used by a significant amount.
4. Energy use in the model is 145 BTU/ton-mile. Data from the IMO suggests that this should be 335 BTU/ton-mile plus 283 BTU/ton-mile for the backhaul. This would increase the ocean shipping emissions by 17.0 g CO_2eq/MJ, a very significant difference.

Summary

With respect to the four questions that were investigated we find that:

1. There are inconsistencies between some aspects of the sugarcane ethanol pathway and all other pathways.
2. There are key input parameters that should be specified by the user of the model. These would include; the share of cane transported by MD and HD trucks, the ocean shipment size, and confirming that a backhaul is always provided.
3. The model does not reflect actual practice. The lack of change in the farming emissions with the different practices that are employed is problematic. The ocean shipping size is double the typical shipments.
4. The background data in the model is not accurate. Although the biggest issue is with the energy used for ocean shipping, the emission factor applied to cane burning should also be changed.

In addition, there are some programming errors in the calculator that need to be adjusted. The following two tables itemize the changes that should be made to the model.

Table ES- 1 Summary of Changes - Farming

Stage	Manual Harvest			Mechanical Harvest		
	Default	Revised	Change	Default	Revised	Change
All Diesel	4.65	5.39	0.74	4.65	5.39	0.74
Extra Diesel for Mech Harvest					7.54	2.15
Extra N Fert for manual	3.22	4.43	1.21			
N_2O from extra N	2.88	3.96	1.08			
Total			3.03			2.89

Table ES- 2 Changes to Rest of Pathway

Item	Default	Revised	Change
N_2O EF	7.48	10.31	2.83
Residue Leaching		7.13	-0.35
Straw Burning EF	10.06	14.42	4.36
Power Export	-0.72	-0.76	-0.04
Shipping			
Backhaul (default value)	7.16	11.41	4.25
Ship size (default value)		18.88	7.47
Int'l Marine Org. Energy		24.15	5.27
Total			23.79

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1. INTRODUCTION

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Based on stakeholder comments received in both the original 2009 rulemaking and the 2011 amendments, the Board directed staff in Resolutions 09-31 and 11-39 to consider revisions to the regulation in a number of specific areas, including the approval of additional fuel pathways. Additionally, staff has indicated that it has conducted internal reviews of lessons learned and has been assessing what has changed since the initial implementation of the LCFS. It is evident that evaluating fuel pathways is very resource-intensive.

Furthermore, stakeholders have expressed concerns that many of the Method 2 pathways in the Lookup Table and on the Method 2 web site are not available for wider use by regulated parties.

In order to attempt to address these issues with fuel pathway certifications, staff is proposing a two-tiered system in which conventionally produced first-generation fuels, such as starch- and sugar-based ethanol, would fall into the first tier. Next-generation fuels, such as cellulosic alcohols, would fall into the second tier.

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1.1 SCOPE OF WORK

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Finally it is important that the model contains the best available background data and that the model functions properly. Background data would include the default values, biomass and fuel characteristics, and other inputs.

The report follows the structure of the model. The following sections consider the sugarcane farming operations, straw burning, can transportation, ethanol production, and ethanol transport from Brazil to California.

The model contains four basic sugarcane ethanol pathways:

- Sugarcane Ethanol – Base Case
- Sugarcane Ethanol – with Power Export
- Sugarcane Ethanol – Mechanized Harvest
- Sugarcane Ethanol – Mechanized Harvest with Power Export.

The values that are on the T1 Calculator sheet in the user input cells are not necessarily the expected user values for those cells so there are no default values per se for the four pathways. The direct CI values in the following table are therefore indicative of differences between the four pathways. These do not include the denaturant and the ILUC values.

Table 1-1 Sugarcane Ethanol Indicative CI Values

	Base Case	Power Export	Mechanized Harvest	Mechanized Harvest with Power Export
	g CO_2eq/MJ			
Farming energy	4.65	4.65	4.65	4.65
Fertilizers	4.67	4.67	4.67	4.67
N_2O in Soil	7.48	7.48	7.48	7.48
Straw Burning	10.06	10.06	10.06	10.06
Cane Transportation	1.29	1.29	1.29	1.29
Mechanized Harvesting Credit	0.00	0.00	-10.06	-10.06
Filter Cake T&D	0.01	0.01	0.01	0.01
Plant Energy	2.30	2.30	2.30	2.30
Ethanol T&D	7.16	7.16	7.16	7.16
Power Credit	0.00	-0.72	0.00	-0.72
Total	37.62	36.90	27.56	26.84

Not all sugarcane plants will be able to use the calculator as their operations do not fit the four cases. These include fields that are burned and mechanically harvested and mechanically harvested fields that collect some of the residue to supplement the bagasse for power generation. These kinds of plants will have to follow a Tier 2 method.

CARB have also been allowing some plants that produce sugar and ethanol to reduce the sugarcane production emissions through the use of economic allocation between the sugar and the molasses that is used for the ethanol feedstock. The calculator could not be used for those plants. Economic allocation is the least preferred approach under ISO LCA guidelines. The plants that co-produce sugar and ethanol should have the available data on energy use in distillation and in crystallization to be able to undertake the CI calculation without any allocation.

2. SUGAR CANE FARMING

The CA GREET model has no user inputs for farming energy, fertilizer, and N_2O emissions. Nor do these values change with the two process modifiers (mechanical harvest and power credit). This is consistent with the other biofuel pathways, where feedstock production values are fixed by the model, but there is a difference in mechanical vs. manual harvest in terms of the fuel energy used and some other parameters.

2.1 ENERGY

Farming energy in the model is supplied by diesel, LPG, gasoline, natural gas, electricity, and renewable natural gas. The default values and their contribution are summarized in the following table. While one can change the default values, they don't go anywhere in the model. The small amount of natural gas on the T1 Calculator sheet is not included in the model.

Table 2-1 Farming Energy

Fuel	Value, BTU/tonne	GHG emissions, g CO_2eq/MJ
Diesel Fuel	36,385	2.061
Gasoline	11,685	0.654
Natural Gas	20,425	0.954
LPG	17,860	0.881
Electricity	8,550	0.092
Renewable Natural gas	95	0.000
Total	95,000	4.642

The sources for the energy use in farming report the energy consumption as diesel fuel per tonne of cane, so it is not clear where the breakdown of fuel use by fuel type came from. If all of the fuel was diesel fuel, then the emissions would increase to 5.39 g CO_2eq/MJ (an increase of 0.75 CO_2eq/MJ).

The 95,000 BTU/tonne was introduced in GREET1 2011 and was about twice as high as the previous value, which used data from 2002. It was suggested by Dunn et al (2011) that the reason for the increase could be due to the increase in mechanical harvesting. A recent paper by Wang et al (2014) considered changes in the Brazilian sugarcane industry between 2010 and 2020. The diesel fuel parameters used in that study are shown in the following table.

Table 2-2 Sugar Cane Farming Parameters

	2010	2015	2020
Yield, tonnes/ha	70.5	80.0	84.0
Mechanical Harvest rate, %	50	80	100
Diesel Fuel consumption, l/ha	230	280	314
Diesel, l/tonne	3.26	3.50	3.92
Diesel, BTU/tonne	110,600	118,800	133,000

The energy use is all higher than is found in CA GREET. This data indicate that the farming energy for manual harvesting should be about 2.4 l/tonne (81,000 BTU/tonne) and for 100% mechanical harvest it should be at least 3.9 l/tonne (133,000 BTU/tonne) and not the same for both cases. This difference in farming energy should be very simple to implement in the CA GREET model.

2.2 FERTILIZERS

The fertilizer parameters are also set in CA GREET and are not to be adjusted by users. The default values and their impact on the GHG emissions from the manufacturing of the fertilizers are shown in the following table. The values on the T1 Calculator tab do not leave the sheet.

Table 2-3 Fertilizer Parameters

Component	Input	GHG Emissions, g CO2eq/MJ
Nitrogen, g/tonne	800.00	3.22
P_2O_5, g/tonne	300.00	0.11
K_2O, g/tonne	1,000.00	0.21
$CaCO_3$, g/tonne	5,200.00	0.71
Herbicide, g/tonne	45.00	0.39
Insecticide, g/tonne	2.50	0.02
Total		4.66

There is a range of fertilizer rates that can be found in the literature. The values used in GREET are within the range and are generally weighted to the more recent data such as the Seabra et al. 2011 report. It is obviously the nitrogen rate that has the largest impact and the earlier version of GREET, such as 1.8d used 1091.7 g/tonne of cane.

It is likely that one of the reasons for a trend to lower nitrogen inputs is the increase in mechanical harvesting and the elimination of the straw burning. This increases the nitrogen in the crop residues that are returned to the soil. The nitrogen content of the residues that are not burned during a mechanical harvest were estimated by Fortes et al (2013) to be 41 kg/ha, or 512 g/tonne at an 80 tonne/ha yield. This is consistent with the reduction N fertilizer seen over the past decade and the reduction in straw burning that accompanies the increase in mechanical harvesting.

The conclusion is that, like the farm energy, it is not appropriate to use the same fertilizer parameters for all four scenarios. There should be different parameters for the manual harvest from the mechanized harvest. The manual harvest should have higher nitrogen inputs than the average values in the model and the mechanized harvest should be lower than the current model value.

2.3 N_2O EMISSIONS

The N_2O emissions in the CA GREET model are fixed at 7.48 g CO_2eq/MJ. None of the user inputs have an impact on this value. There are two factors that have an impact on the calculation: the total quantity of nitrogen applied, and the N_2O emission factor applied. These are discussed below.

2.3.1 Nitrogen Applied

The nitrogen applied is the sum of the synthetic nitrogen fertilizer, nitrogen applied through amendments such as vinasse application, and the above and below ground crop residues. The values in the CA GREET model are listed below.

Table 2-4 Nitrogen Additions to the System

Source	Quantity, g/tonne	CO_2eq Emissions, g/MJ
Synthetic Fertilizer	800	2.88
Crop Residue	1,036	3.73
Filtercake	36	0.13
Vinasse	205	0.74
Total	2,077	7.48

In the CA GREET model the crop residue value is independent of the type of harvest. The model assumes that the nitrogen in the crop residue is returned to the soil as ash. However the data on the fertilizer that is applied does not appear to support this. If the nitrogen in the burned residue is returned to the soil it is not likely returned to the sugarcane field but at some other land.

The proportion of nitrogen from fertilizer and from crop residue should vary depending on whether or not there is straw burning.

2.3.2 N_2O Emission Factor

The model uses the basic IPCC Tier 1 emission factors for the synthetic nitrogen and the crop residues. This includes the direct emissions of N_2O from nitrogen and crops residues, the emissions from nitrogen that is leached from the site and run-off, and the emissions from volatilization of some of the applied nitrogen. This is a misapplication of the IPCC methodology as there should be a small difference between the emission factor for crop residues, which have no volatilization impact and the synthetic fertilizer which does have a volatilization factor. If the factor for synthetic nitrogen is 1.325%, the value for the crop residue should be 1.225%. The 1.325% is made up of:

- 1% of the nitrogen in the synthetic nitrogen and crop residues is emitted as N_2O (EF1).
- 10% of the synthetic nitrogen is volatilized and 1% of that is emitted as N_2O.
- 30% of the N applied is leached or run-off and 0.75% of that is emitted as N_2O.
- Total is 1% + 0.1*1% + 0.3*.075% = 1.325%

The larger issue is whether or not the IPCC Tier 1 default value for EF1 of 1% is appropriate for this region of the world. N_2O emissions are influenced by soil type, precipitation, topography, temperature, and other factors. The GREET model has applied some different factors for different crops but the CA GREET model has applied the same factors for all crops. This will result in underestimating the emissions for some crops and overestimating the emissions for other crops.

2.3.2.1 *The Scientific Literature*

Sugarcane has a high need for moisture and there is evidence that the N_2O emission factor should be higher due to high levels of precipitation. Renouf et al (2010), in a study of Australian sugarcane production, use an average value of 0.04 for EF1 and report a range of 0.01 to 0.07. Thorburn et al (2010) modeled the N_2O emissions from sugarcane production systems in Australia and determined a range of N_2O emissions form 3-5% of fertilizer applied. Denmard et al (2010) measured N_2O emissions at two sites in Australia and found a range of emissions from 2.8 to 21% of nitrogen in applied fertilizer. The Australian national GHG inventory applies a value of 1.25% for EF1 but it is not clear if this is a Tier 2 value, or simply the Tier 1 value from the 1995 guidelines.

Lisboa et al (2011) looked at this issue for sugarcane production. In addition to the data from Australia they also found data for Hawaii. They determined that the average N_2O emission rate was 3.87%, however while they compare this value to the IPCC EF1 value, they are not comparable. The 3.87% is the total N_2O emissions based just on the nitrogen applied with synthetic fertilizer. It does not include the nitrogen applied from residue or other sources, nor does it include the N_2O from nitrogen leached from the site. Including these would lower the emission factor.

Although information on N_2O emissions for Brazilian sugar cane production is more limited a recent paper by Walter et al. (2014) reported:

> *Experiments in Australia comparing burnt and unburnt harvesting systems indicate that the maintenance of sugarcane straw on the field increases soil N_2O. These results have been recently corroborated by field experiments conducted in Brazil, but with an even more marked increase when vinasse is applied. Because the soil–atmosphere exchange of N_2O depends on complex interactions, more regional and site-specific data are needed to evaluate the impact of this source on the overall GHG balance of biofuels.*

Signor et al (2013) measured the N_2O emissions from sugar cane production at two sites in Brazil. At the first site the proportion of N lost as N_2O ranged from 0.80 to 12.95%. At the second site N_2O emissions varied from 1.22 to 1.53% of added N for ammonium nitrate treatments and from 0.31 to 1.10% for urea.

Experiments reported by da Silva Paredes (2014) found the highest proportions of N emitted as N_2O were registered in the vinasse treatment, which amounted to 15 % of the N applied in the first greenhouse experiment, and 2.5 % in the field experiment, however the N_2O emission rate for just urea were considerably below the Tier 1 default value of 1%.

Vargas et al (2014) investigated the impact of soil moisture and the level of trash retained in the soil and found that N_2O emissions increase with soil moisture and the presence of trash on the soil doubled the impact of increasing soil moisture on N_2O emissions.

Although there is significant uncertainty with respect to the N_2O emission factor for sugar cane production in Brazil, the scientific literature indicates that rates are higher when the fields are not burned and the trash remains on the field. Rates are also higher when vinasse is applied to the field. More work has been done in Australia and corroborated with field experiments in Brazil, and all of that work suggests that the appropriate emission factor is greater than the 1% value for EF1 that has been used by CARB.

2.4 SUGAR CANE FARMING SUMMARY

The CA GREET model does not apply different energy use factors to sugar cane farming even though the two scenarios with mechanical harvesting require almost twice the energy of a manual harvest system. A mechanical harvest system with 100% of the energy supplied by diesel fuel will have GHG emissions of 7.54 g CO_2eq/MJ.

There is evidence that the crop residues that are left on the field are reducing the synthetic nitrogen that is required. The proportion of nitrogen from fertilizer and from crop residue should vary depending on whether or not there is straw burning. The CA GREET model is assuming that there is no difference in nitrogen requirements between burned and unburned fields, an unlikely scenario.

Although there is significant uncertainty regarding the appropriate N_2O emission factor for sugar cane production, the best information in the peer reviewed literature indicates that the 1% EF1 factor used by CARB is too low. The impact of increasing this to 1.5% is an increase in sugar cane N_2O emissions of 2.83 g CO_2eq/MJ.

3. STRAW BURNING

For fields that are not mechanically harvested the CA GREET model assumes that the fields are burned prior to harvesting. This does result in different values for the manual versus mechanical harvested scenarios, where a credit for the burning emissions is introduced in the mechanical harvesting systems.

In the GREET model all of the nitrogen in the straw is included in the crop residue whether the straw is burned or is left on the soil. This is not likely to be the case but correcting it would result in lower emissions for fields that are burned and no change in the emissions for mechanical harvesting.

Even though the straw is biogenic the methane emissions and the N_2O emissions must still be included in the calculations of GHG emissions. The emission factors used in GREET are shown in the following table.

Table 3-1 Straw Emission Factors

	CA GREET	IPCC Grassland	IPCC Ag residue
	g/tonne		
Methane	2,700	2,300	2,700
N_2O	7	21	7

CA GREET also converts the CO and VOC emissions to CO_2eq for straw burning and then provides a credit for the carbon uptake from the atmosphere. This essentially uses the biogenic methane GWP factor of 22.25.

The IPCC values shown above are for grassland burning and for Ag residue burning, as there are no specific emission factors for sugarcane field burning. The source of the IPCC estimates is the paper by Andrea & Merlet (2001). In that paper there are over 40 references to support the grassland estimates and the note beside the Ag residue value is “Value is a best guess”.

The GHG emissions for straw burning would increase to 14.42 g CO_2eq/MJ if the IPCC Grassland values were used rather than the Ag residue values.

3.1 STRAW BURNING SUMMARY

The straw burning emissions are too low by about 4.43 g CO_2eq/MJ as a result of using the IPCC emission factors for Ag residue burning rather than the values for grassland and savanna burning. This increase would be reduced to about 2.5 g CO_2eq/MJ if the nitrogen from the burned straw was not returned to the soil as discussed in the previous section.

4. CANE TRANSPORTATION

The cane transportation distance is a user input to the CA GREET model. They have modelled both a medium duty and a heavy duty truck. This is appropriate because both types of trucks can be used, although they have assigned a 100% share to both types and the share is not a user input. Either one or the other will be used, not both. The share should also be a user input.

The same energy use is used for HD and MD trucks for all pathways in the model. Sugar cane transport it usually at lower speeds than highway travel in North America but the roads are generally dirt, so the assumption of the same energy use is probably reasonable.

The transportation distance is the user input and it is the key parameter in driving the GHG emissions.

4.1 CANE TRANSPORT SUMMARY

The model should be changed so that the share of the delivery of cane by medium duty trucks and by heavy duty trucks is a user input. The truck energy requirements are the same as for corn ethanol.

5. Ethanol Plant

The GHG emissions from the ethanol plant stage using the default values in the CA-GREET model amount to 2.30 g CO_2eq/MJ, or less than 10% of the lifecycle emissions for each of the 4 scenarios. The composition of the total is discussed below.

5.1 Energy Use

The T1 Calculator sheet asks for total energy use in the mill by type of energy. The calculator as produced only includes some residual oil use and some electric power use. It has zero for biomass use. All of the 2.30 g CO_2eq/J of emissions are energy derived.

Sugar cane mills burn a lot of bagasse to provide the power and the steam for the mills. This biomass is hardcoded into the model and is not adjusted when a user enters biomass energy into the T1 Calculator sheet. It is also not included in the energy consumption values. If a mill imported bagasse or straw to produce more electricity, the model will not produce higher emissions as a result of the higher biomass inputs.

The contribution of the default energy values to the total for this stage is shown in the following table. Even though the bagasse is biogenic the methane and N_2O emissions are still included in the calculations.

Table 5-1 Ethanol Plant Energy Related Emissions

Type	Value	Emissions
	BTU/gal	G CO_2eq/MJ
Residual oil (10% loss of lubricants)	300	0.04
Power	24.37	0.00
Bagasse	89,272	2.26
Total	89,596.37	2.30

Most of the emissions are related to methane and N_2O emissions from burning the bagasse. It is not clear on the T1 Calculator sheet that the residual oil use is related to lubricants and users will likely try and zero this value out when they use the calculator.

5.2 Chemicals

The two chemicals that are included in the T1 Calculator sheet are sulphuric acid and ammonia. Both are zero in the model. Seabra (2011) reports sulphuric acid consumption in the mills of 0.0074 kg/litre, 28 g/gal. The model is broken as it transfers the 28 g of sulphuric acid to cell DU 357 (Alpha Amylase) on the EtOH sheet rather than to DU 361 (Sulphuric Acid). This results in GHG emissions of 169,460 g CO_2eq/MJ for the ethanol production stage, an obvious error. The ammonia also goes to the wrong cell on the EtOH sheet.

The CA GREET model for Tier I applications doesn't apply to mills that produce sugar and ethanol. These need to be done using the Tier 2 methodology, but are still expected to be done using the CA GREET model as the base. These mills use some lime in the production process (Seabra reports 42.6 g/gal). There is no provision in CA GREET for including lime as an input to the ethanol production process. This needs to be added as user input. Lime has GHG emissions of about 1.25 g/g CAO so including this chemical would add about 0.7g CO_2/MJ to the ethanol production emissions.

5.3 POWER EXPORTS

The new CA-GREET model is using the average power mixes rather than trying to estimate the marginal power in all of the different regions that are included in the model. In the case of Brazil, this drastically lowers the credit for power exports.

There is an error in the CA-GREET model with respect to the Brazilian power mix. When the data is migrated from the T1 Calculator sheet to the ETOH sheet the values for nuclear and biomass power are transposed. The values in cells Q293 and Q294 on the ETOH sheet are therefore incorrect and lead to a slightly higher credit (~0.1 g/MJ) than should be calculated.

A larger issue is the quality of the data being used in the model for Brazil power. The power mix for Brazil that is used in CA-GREET is shown in the following table. The source identified for the data is the US DOE EIA country brief. This brief was updated in December 2014 and the results are also shown in the table. Small amounts from wind, solar, and nuclear made up the rest.

Table 5-2 GREET Brazil Power Mix

	Brazilian Mix in Model	Updated EIA Brief
Resid Oil/Fossil fuels	0.00%	4%
Natural gas	11.00%	11%
Coal	0.00%	0%
Nuclear power	2.00%	0%
Biomass	7.00%	8%
Hydroelectric	55.76%	71%
Geothermal	3.33%	0%
Wind	20.65%	0%
Solar PV	0.26%	0%
Others (purchased)	0.01%	0%
Total	100.01%	94.00%

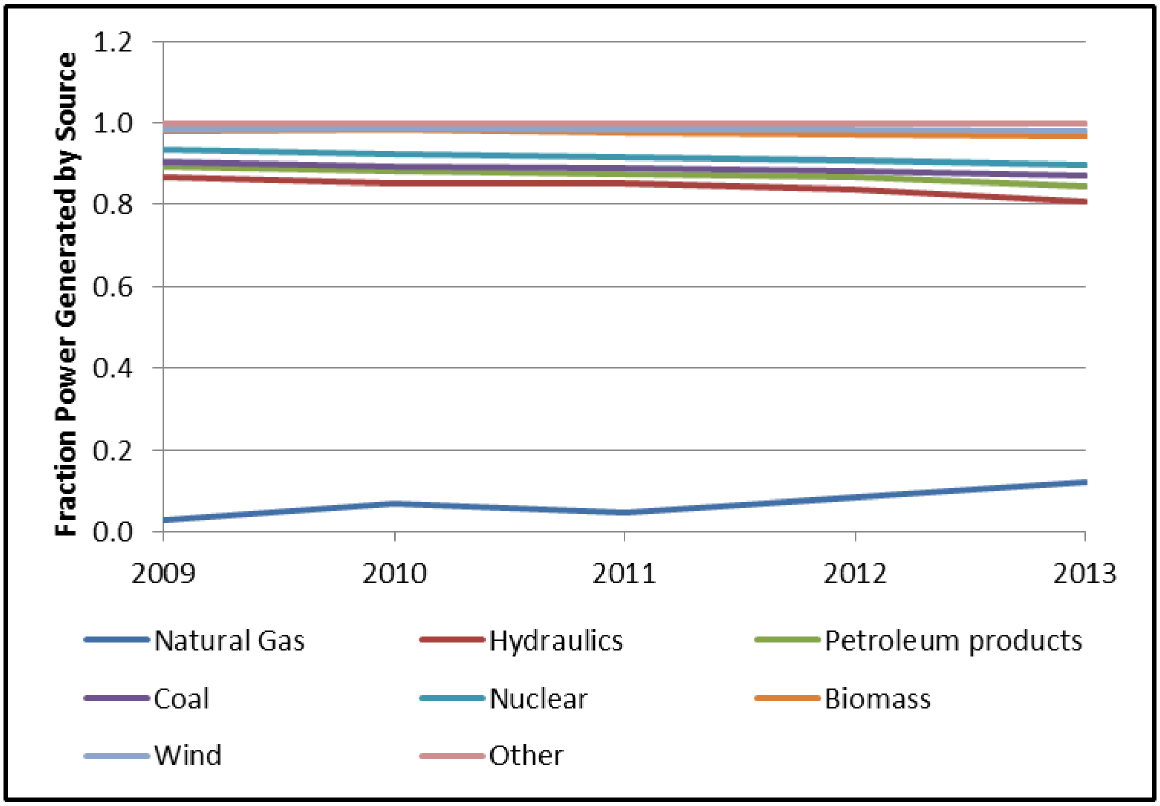
There is a better source of electrical power generation in Brazil. The Energy Research Company - EPE publishes a Statistical Review of the Electric Sector (EPE, 2014). The information from that source is shown below.

Table 5-3 Actual Brazil Power Mix

	2009	2010	2011	2012	2013
Natural Gas	2.86%	7.07%	4.72%	8.46%	12.11%
Hydro	83.87%	78.19%	80.55%	75.18%	68.59%
Petroleum products	2.73%	2.76%	2.30%	2.93%	3.88%
Coal	1.16%	1.36%	1.22%	1.52%	2.60%
Nuclear	2.78%	2.82%	2.94%	2.90%	2.57%
Biomass	4.69%	6.05%	5.95%	6.27%	6.96%
Wind	0.27%	0.42%	0.51%	0.91%	1.15%
Other	1.64%	1.34%	1.81%	1.81%	2.15%
Total	100.00%	100.00%	100.00%	100.00%	100.00%

CARB underestimates the natural gas, coal, and oil used for power generation in Brazil. Furthermore the quantity of gas being used is increasing with time as shown below. The fossil fuel fraction has increased 275% since 2009.

Figure 5-1 Power Generation Trends



Using a more accurate estimate of the Brazilian power mix will slightly increase the base emissions but also increase the power credit available for plants that export power to the grid.

5.4 Ethanol Production Summary

There are several errors in the CA GREET model related to the transfer of information from the T1 Calculator sheet to the core of the model. These include:

1. Nuclear and biomass power shares of the power generation are transposed when they are transferred to the ETOH sheet.
2. The inputs for sulphuric acid and ammonia are input into the cells for enzymes when they move from the T1 Calculator sheet to the ETOH sheet. Entering non-zero values will produce extremely high and erroneous GHG emissions.

There is also the potential for misinterpretation of the input values. The input for Residual oil is really the quantity of used lubricants that are burned in the plant and not the input of residual oil.

The quantity of biomass that is burned at the plants is hard coded in the model. Not all mills burn all of the bagasse on site; some sell a portion to other local industries. The emissions for these operations will be overestimated. The biomass from the T1 Calculator sheet is transferred to the ETOH sheet, but once it goes there it is not included in any calculations. Proper modelling should require the mills to enter the bagasse consumed and not hard code those quantities. The current model would underestimate the emissions from mills that imported bagasse from another facility or used some straw from the fields to produce more electric power for export.

6. ETHANOL TRANSPORTATION

Ethanol can be transported from Brazil to California by truck, rail, and pipeline in Brazil, by ocean tanker, and then by truck in California. In CA-GREET the user will select the transportation distances and the distances for each mode on the T1 Calculator sheet. The values in the calculator create emissions of 7.16 g CO_2e/MJ with only the Brazilian truck, ocean freight and the California Port to blending stations being non-zero inputs. The distance from the blending point to the service station is a non-adjustable system input for all types of ethanol; however the distance is different for sugarcane ethanol compared to corn ethanol (50 miles vs. 40 miles). They should be the same.

Table 6-1 Transportation Emissions

Mode	Distance	Emissions
Brazil Truck	130	1.01
Ocean Ship	8,758	5.06
US Truck	90	0.70
Truck to Service Station	50	0.39
Total		7.16

The Brazilian trucking distance is short but that will have to be filled in by the applicant for the specific mill.

The issue for modelling is the calculation of the ocean shipping emissions. There are three issues with the calculation which lead to an inaccurate assessment of the emissions. These are described below.

6.1 BACKHAUL

All of the ocean movements in the CA GREET model, ***except Brazilian ethanol***, have an energy charge for the primary movement and the backhaul movement. This backhaul charge is 84% of the energy of the one-way movement. There is no backhaul charge for the Brazilian ethanol. If there was, the emissions would increase by 3.43 g/MJ. The model should be revised to include backhaul as a default value whenever an applicant cannot prove that there will be no backhaul for the relevant pathway.

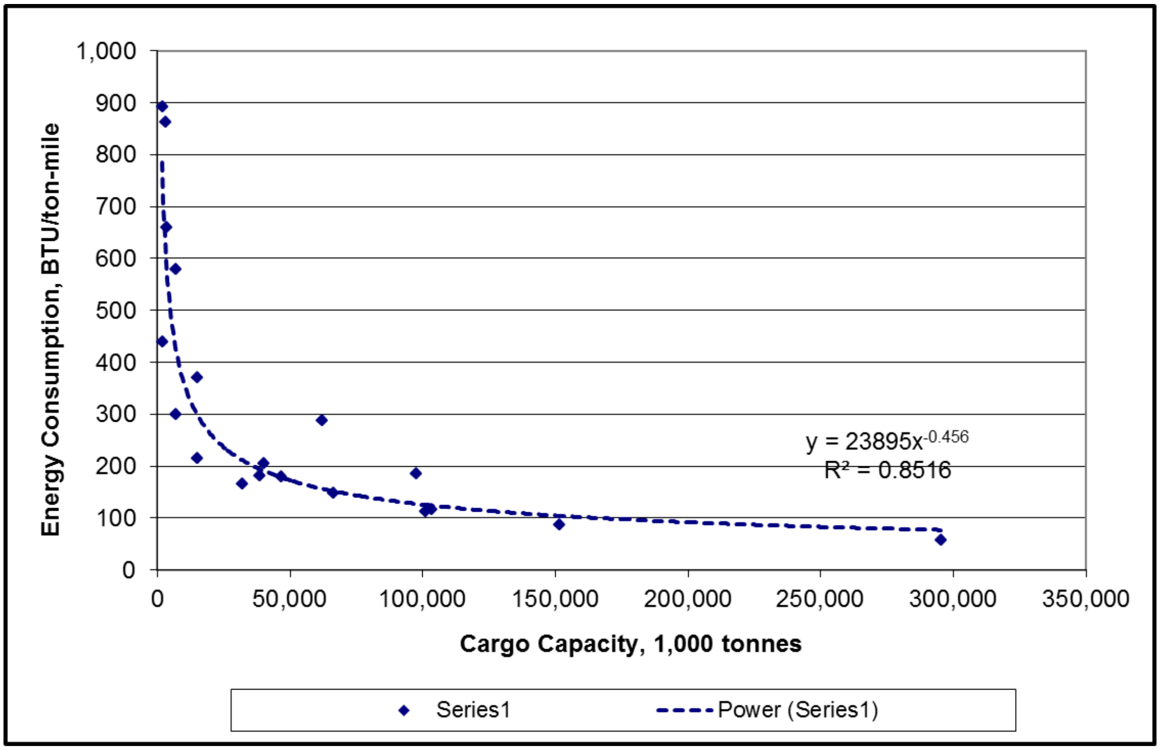
6.2 SHIPMENT SIZE

The CA GREET model assumes that the ethanol is delivered in 22,000 tons shipments. The US DOE EIA reports petroleum product imports on a company level basis. The 2014 data for the first 10 months of the year is currently available. Sugarcane ethanol from Brazil, Guatemala, and Nicaragua has been received in the US. No Brazilian ethanol has been landed in California during this time period. The average size of the shipment was 11,200 tons. This includes shipments that were delivered to more than one port as a single load of the combined capacity. This is only half of the value in the model and it will result in the energy and thus the emissions being underestimated. The model should be revised to require a verifiable shipment size as a user input.

6.3 VESSEL ENERGY REQUIREMENTS

The size of the ship has a large impact on the energy expended; larger ships require less energy to move the cargo. The International Maritime Organization (IMO, 2008) published data on the GHG emissions for various sizes of ships. The GHG emissions are easily converted to energy and the relationship for a range of chemical, petroleum product, and crude oil carriers are shown in the following figure. The energy consumption is very sensitive to vessel size, especially for the small vessels, and the energy can increase by 50% of more moving from a 22,000 ton vessel to an 11,000 ton vessel.

Figure 6-1 Energy Requirements vs. Vessel Size



The energy use for the 22,000 ton shipment in GREET is 140 BTU/ton-mile and it excludes the backhaul. The IMO estimate for an 11,000 ton shipment is 343 BTU/ton-mile. To this would be added the 84% for a back haul, for a total energy use of 631 BTU/ton-mile or 4.5 times more than the CA GREET model estimates. This would add about 17.5 g/MJ to the Brazilian sugarcane ethanol carbon intensity for pathways that cannot verify that there is no backhaul.

The calculation of energy consumption in GREET is based on theoretical calculations, includes some erroneous correlations, and underestimates the real world energy use. For example, the faster a ship travels the more power is consumed, but in GREET the energy consumption decreases with faster travel. This is because the power requirements increase as the cube of the velocity in the real world but in GREET the power requirements are independent of the speed. The energy consumed per mile is a function of the square of the speed, or power divided by speed. GREET uses the power/speed equation but doesn't account for the power being a function of the speed, so the end calculated result is incorrect. The model must be revised to correct the errors.

6.4 TRANSPORTATION SUMMARY

There are significant issues with the ocean shipping calculations in GREET for many of the fuels, including sugarcane ethanol. The issues for sugar cane ethanol include:

1. The shipment size of 22,000 tons is too high and is not a user input.
2. Sugar cane Ethanol from Brazil, uniquely of all of the fuels in CA GREET, is not charged with a backhaul.
3. The energy use for ocean shipping is calculated but the calculations underestimate the energy used by a significant amount.
4. Energy use in the model is 145 BTU/ton-mile. Data from the IMO suggests that this should be 335 BTU/ton-mile plus 283 BTU/ton-mile for the backhaul. This would increase the ocean shipping emissions by 17.0 g CO_2eq/MJ, a very significant difference.

7. Discussion

The sugar cane ethanol pathway in the new CA GREET 2.0 model has been thoroughly reviewed. The review has considered the following questions.

- Are the pathways consistent?
- Does the model ask for the key input parameters?
- Does the model reflect the actual practices?
- Does the model have the correct background data and are the calculations correct?

A significant number of issues were identified. Most of the issues results in the model returning values that are lower than what would be returned if the issues were addressed properly.

7.1 Sugar Cane Farming Summary

The CA GREET model does not apply different energy use factor to sugar cane farming even though the two scenarios with mechanical harvesting require almost twice the energy of a manual harvest system. A mechanical harvest system with 100% of the energy supplied by diesel fuel will have GHG emissions of 7.54 g CO_2eq/MJ.

There is evidence that the crop residues that are left on the field are reducing the synthetic nitrogen that is required. The proportion of nitrogen from fertilizer and from crop residue should vary depending on whether or not there is straw burning. The CA GREET model is assuming that there is no difference in nitrogen requirements between burned and unburned fields, an unlikely scenario.

Although there is significant uncertainty regarding the appropriate N_2O emission factor for sugar cane production, the best information in the peer reviewed literature indicates that the 1% EF1 factor used by CARB is too low. The impact of increasing this to 1.5% is an increase in sugar cane N_2O emissions of 2.83 g CO_2eq/MJ.

7.2 Straw Burning Summary

The straw burning emissions are too low by about 4.36 g CO_2eq/MJ as a result of using the IPCC emission factors for Ag residue burning rather than the values for grassland and savanna burning. This increase would be reduced to about 2.5 g CO_2eq/MJ if the nitrogen from the burned straw was not returned to the soil as discussed in the previous section.

7.3 Cane Transport Summary

The model should be changed so that the share of the delivery of cane by medium duty trucks and by heavy duty trucks is a user input. The truck energy requirements are the same as for corn ethanol.

7.4 Ethanol Production Summary

There are several errors in the CA GREET model related to the transfer of information from the T1 Calculator sheet to the core of the model. These include:

1. Nuclear and biomass power shares of the power generation are transposed when they are transferred to the ETOH sheet.
2. The inputs for sulphuric acid and ammonia are input into the cells for enzymes when they move from the T1 Calculator sheet to the ETOH sheet. Entering non-zero values will produce extremely high and erroneous GHG emissions.

There is also the potential for misinterpretation of the input values. The input for Residual oil is really the quantity of used lubricants that are burned in the plant and not the input of residual oil.

The quantity of biomass that is burned at the plants is hard coded in the model. Not all mills burn all of the bagasse on site; some sell a portion to other local industries (San Martinho, 2007). The emissions for these operations will be overestimated. The biomass from the T1 Calculator sheet is transferred to the ETOH sheet, but once it goes there it is not included in any calculations. A proper modelling would require the mills to enter the bagasse consumed and not hard code those quantities. The current model would underestimate the emissions from mills that imported bagasse from another facility or used some straw from the fields to produce more electric power for export.

7.5 Transportation Summary

There are issues with the ocean shipping calculations in GREET for many of the fuels, including sugarcane ethanol. The issues for sugar cane ethanol include:

1. The shipment size of 22,000 tons is too high and is not a user input.
2. Ethanol, uniquely of all of the fuels in CA GREET, is not charged with a backhaul.
3. The energy use for ocean shipping is calculated but the calculations underestimate the energy used by a significant amount.
4. Energy use in the model is 145 BTU/ton-mile. Data from the IMO suggests that this should be 335 BTU/ton-mile plus 283 BTU/ton-mile for the backhaul. This would increase the ocean shipping emissions by 17.0 g CO_2eq/MJ, a very significant difference.

7.6 Summary

With respect to the four questions that were investigated we find that:

1. There are inconsistencies between some aspects of the sugarcane ethanol pathway and all other pathways.
2. There are key input parameters that should be included in the model. These would include, the share of cane transported by MD and HD trucks, the ocean shipment size, and confirming that a backhaul is always provided.
3. The model does not reflect actual practice. The lack of change in the farming emissions with the different practices that are employed is problematic. The ocean shipping size is double the typical shipments.
4. The background data in the model is not accurate. The biggest issue is with the energy used for ocean shipping but the emission factor applied to cane burning should be changed.

In addition, there are some programming errors in the calculator that need to be adjusted. Correcting the issues in the model will increase the GHG emissions in the different scenarios. The following two tables itemize the changes that should be made to the model.

Table 7-1 Summary of Changes - Farming

Stage	Manual Harvest			Mechanical Harvest		
	Default	Revised	Change	Default	Revised	Change
All Diesel	4.65	5.39	0.74	4.65	5.39	0.74
Extra Diesel for Mech Harvest					7.54	2.15
Extra N Fert for manual	3.22	4.43	1.21			
N_2O from extra N	2.88	3.96	1.08			
Total			3.03			2.89

Table 7-2 Changes to Rest of Pathway

Item	Default	Revised	Change
N_2O EF	7.48	10.31	2.83
Residue Leaching		7.13	-0.35
Straw Burning EF	10.06	14.42	4.36
Power Export	-0.72	-0.76	-0.04
Shipping			
Backhaul	7.16	11.41	4.25
Ship size		18.88	7.47
IMO Energy		24.15	5.27
Total			23.79

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